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(54) Demodulating an amplitude modulated signal

(57) In order to reduce signal loss particularly when transmitting data in a quasi-synchronous area coverage scheme utilising sideband diversity it is necessary to effect coherent demodulation by locking the local oscillator signal

to the received carrier signal, even when the carrier has been completely suppressed. A demodulator capable of operating over a wide range of input phase error comprises mixers (48, 50) to which a frequency converted input signal and a local oscillator signal are applied. The outputs of the mixers are applied via respective audio bandpass filters (56, 58) to a further mixer (60) to provide a sideband error signal (E_s) which is low pass filtered (62). A carrier error signal (E_c) is derived by low pass filtering the output of the first mixer (48). A composite error signal E_{cs} is applied to either the local oscillator (52) to lock its frequency and phase to the input signal or to a local oscillator of a preceding frequency conversion stage. In operation when the radio frequency phase angle ϕ approaches 180° then the phase reference tracks across from a stable null at 0° to another stable null at 90° . The stable null tracks to 180° for values ϕ of 270° and greater.

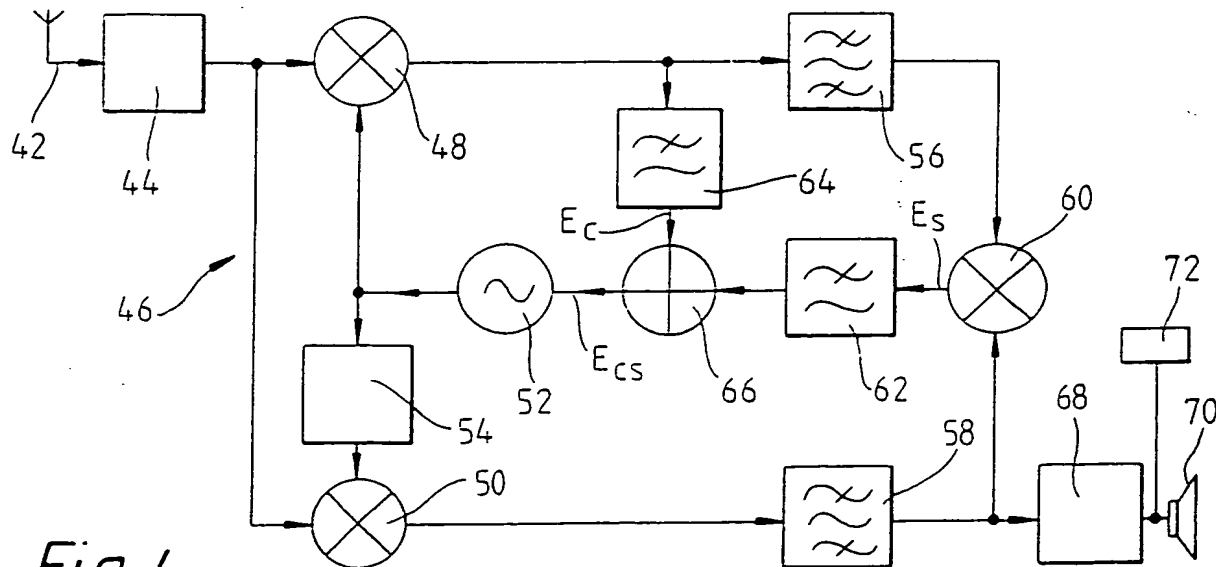


Fig.4.

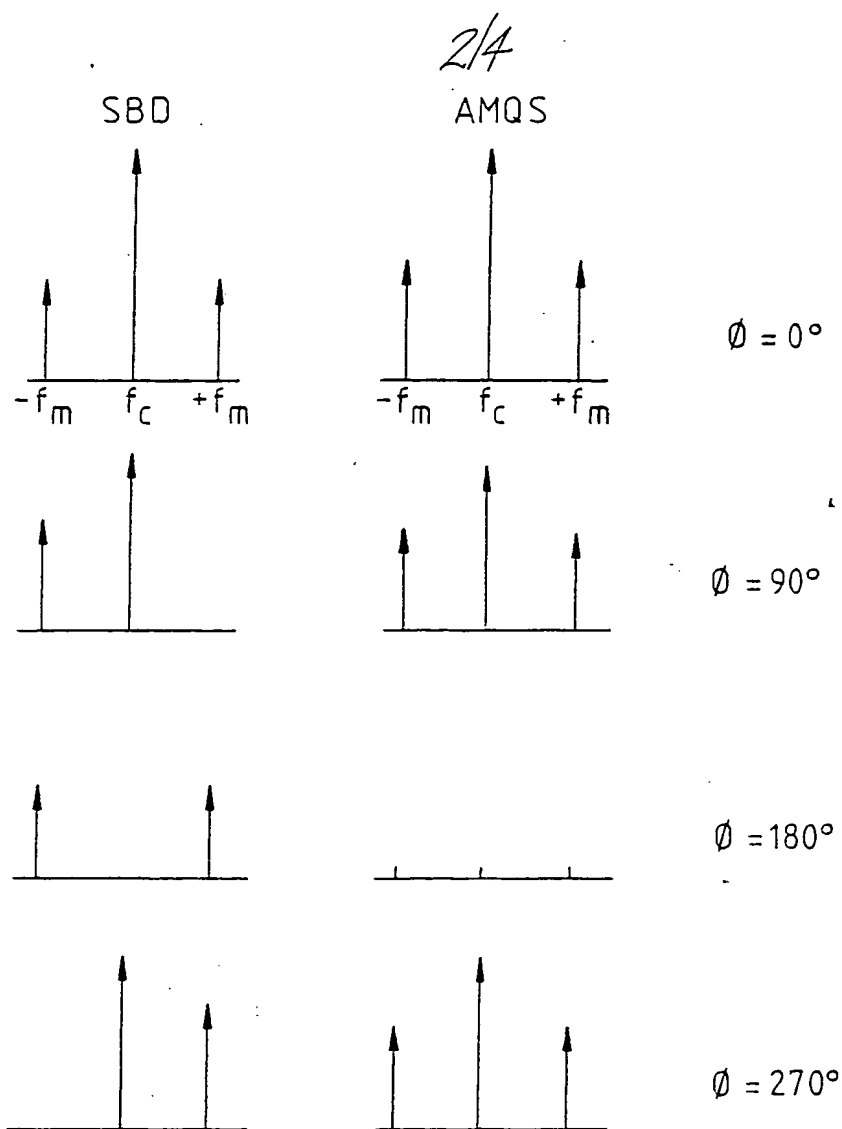


Fig.3.

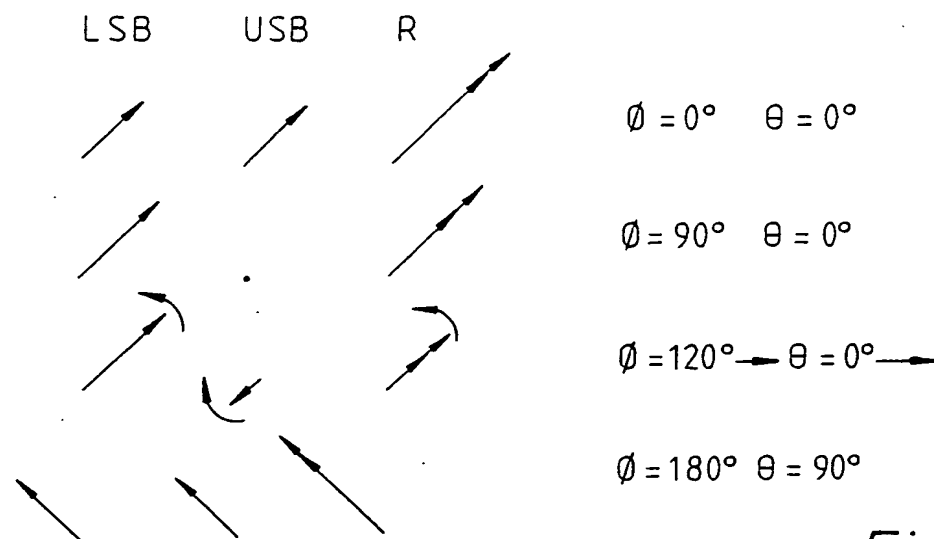


Fig.6.

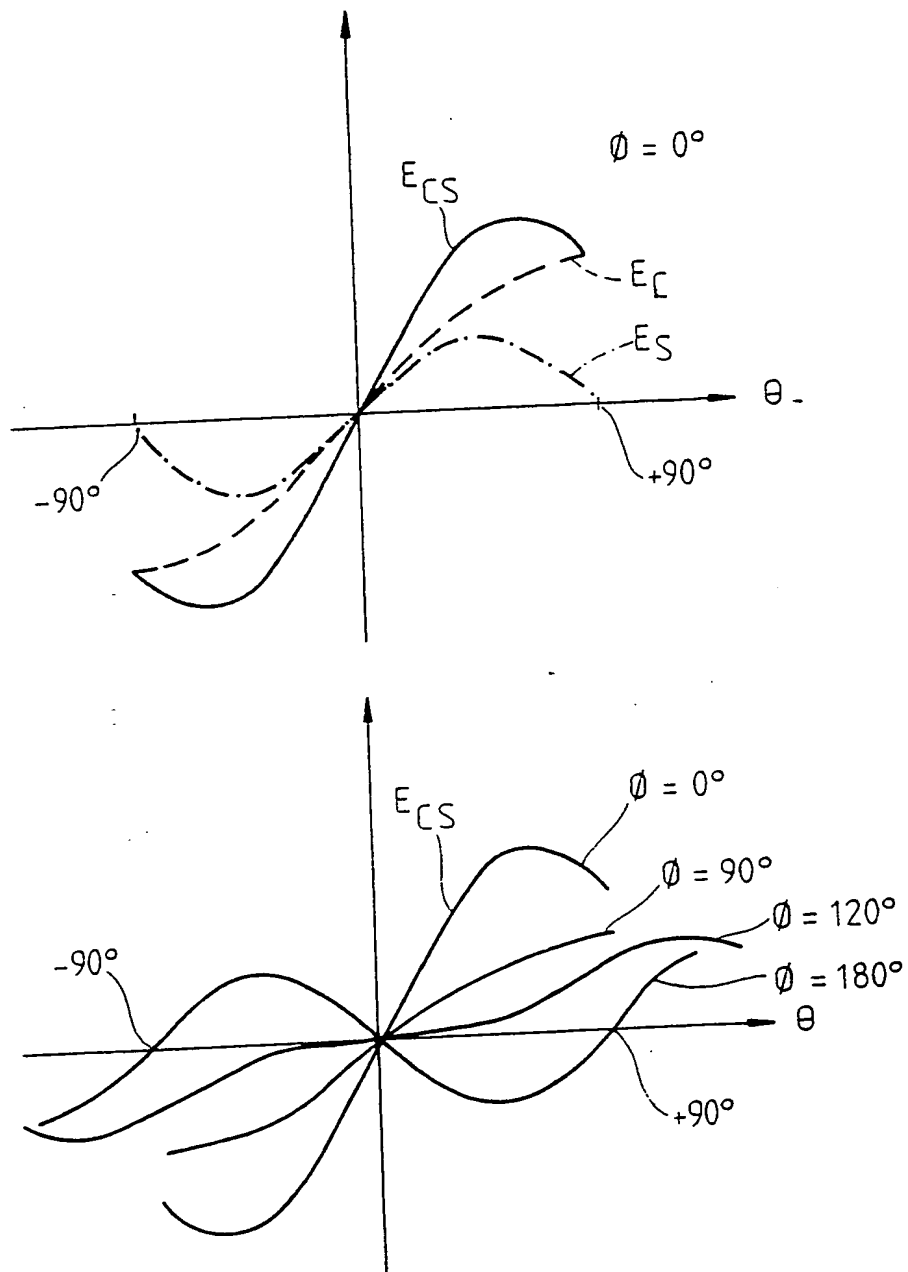
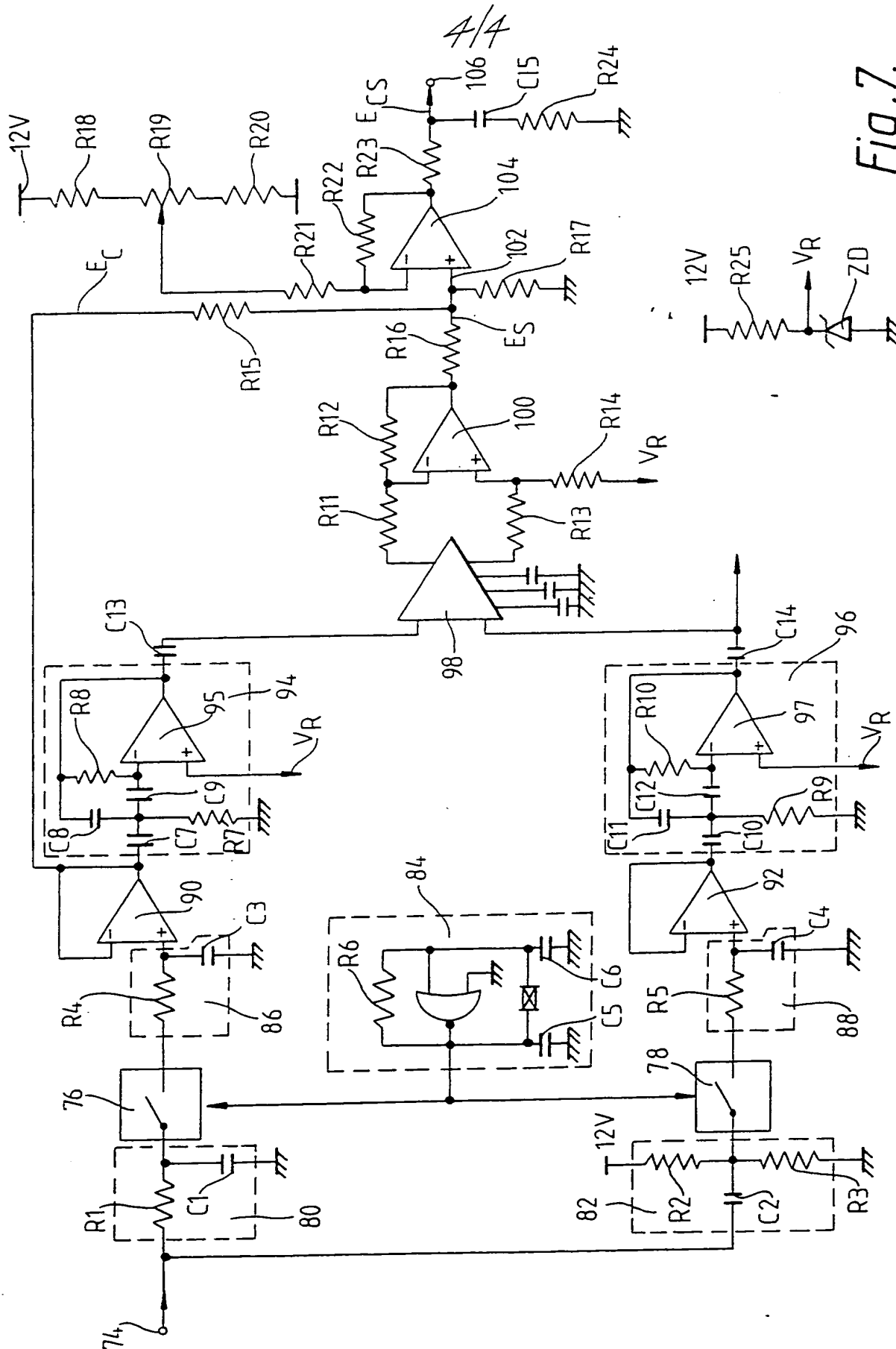
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Fig. 5.



SPECIFICATION

A method of, and a receiver for, demodulating a double sideband amplitude modulated signal in a quasi-synchronous area coverage scheme utilising sideband diversity

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The present invention relates to a method of, and a demodulator for, demodulating a double sideband amplitude modulated (A.M.) signal in a quasi-synchronous (Q.S.) area coverage scheme utilising sideband diversity.

A Q.S. area coverage scheme is a technique extending the coverage area in mobile radio schemes by simultaneous operation of a number of amplitude modulated transmitters, with overlapping service areas and closely spaced carrier frequencies (within a few Hertz of each other). Such Q.S. area coverage schemes have been used in the United Kingdom for speech communication by major users, such as the police.

Quasi-synchronous operation not only extends the coverage area but intensifies the coverage by overcoming shadowing by terrain features and large buildings. In equal signal strength areas however the performance may be degraded by interaction between the several received signals. In areas with no multipath fading a slow beat occurs between the several received signals and when the resultant signal nulls below the receiver threshold there is a consequent loss of audio signal. In multipath fading areas, the fading of the individual transmissions will be uncorrelated by virtue of the geographic spacing of the transmitters. However the interaction between the transmissions causes the resultant signal received at the mobile to exhibit similar fading characteristics.

The dubious performance of Q.S. schemes in signal overlap areas, that is areas where signals from two or more transmitters overlap, is tolerable with speech transmissions because the redundancy of speech ensures that there is rarely any loss of intelligibility. However, there is a growing demand for medium speed data transmission between the base station and mobiles and interaction between transmission in Q.S. area coverage schemes can be a major source of errors. Sideband Diversity described in greater detail in two published articles of which one is entitled "Sideband Diversity: a new application of diversity particularly suited to land mobile radio" published in The Radio and Electronic Engineer, Vol. 48, No. 3, pages 133-139, March 1978 by Professor W. Gosling, J.D. Martin, R.J. Holbeche and G. Allen, and the other of which is entitled "An evaluation of a sideband diversity technique for data transmission on the forward path in a mobile radio area coverage scheme" published in the Radio and Electronic Engineer, Vol. 49, No. 10, pages 521 to 529, October 1979 by G. Allen, R. J. Holbeche and Professor W. Gosling, is a technique that utilises the redundancy of A.M. signals to overcome the interaction between transmissions in Q.S. schemes and in so doing allows the diversity advantage offered by geographically spaced transmitters to be realised in multipath fading environments.

In a Sideband Diversity scheme, a constant phase shift over the audio frequency band is introduced between the modulation applied to the transmitters by wide band phase shift networks. In a two transmitter scheme this phase angle would be 90° and the resultant signal (V_r) received by a mobile is described by:-

$$V_r = 2v. [\cos \delta \omega_c t / 2] \cdot \cos \omega_c t + mv. [\cos(\delta \omega_c t / 2 - 45^\circ)] \cdot \cos(\omega_c t - \omega_m t - 45^\circ) + mv. [\cos(\delta \omega_c t / 2 + 45^\circ)] \cdot \cos(\omega_c t + \omega_m t + 45^\circ) \quad \dots(1)$$

where

v = Common received signal amplitude
 ω_c = Carrier angular frequency
 m = Modulation index
 ω_m = Modulation angular frequency, and
 $\delta \omega_c$ = Frequency offset between the transmitters.

The factor in the square brackets in each term of this expression represents the slow modulation caused by receiving two signals with a small frequency offset that is $\pm \delta \omega_c t / 2$. However the modulation is no longer identical for the carrier and/or the two sidebands and when one sideband is nulled to zero the other one is at a maximum. Thus the information content of the transmission is no longer periodically destroyed as in conventional Q.S. schemes.

When a vehicle is in motion the Doppler shift introduced can reduce the offset frequency to zero or increase it to a maximum value of $(\delta \omega_c + 2\omega_d)$ where ω_d is the Doppler shift, depending upon the direction of motion of the vehicle between the transmitters. Equation (1) can thus be re-written:-

$$V_r = 2v. \cos \phi(t) / 2 \cdot \cos \omega_c t + mv. \cos(\phi(t) / 2 - 45^\circ) \cdot \cos(\omega_c t - \omega_m t - 45^\circ) + mv. \cos(\phi(t) / 2 + 45^\circ) \cdot \cos(\omega_c t + \omega_m t + 45^\circ) \quad \dots(2)$$

where ϕ , the radio frequency phase angle, can take on any value between 0° and 360° and may be stationary or not depending upon the offset frequency.

Conventional demodulators cannot be used to demodulate transmissions in sideband diversity operation because in the case of receiving two equal transmissions, the spectra of the resultant signal changes from a conventional A.M. signal at a radio frequency phase angle $\phi = 0^\circ$ to single sideband at $\phi = 90^\circ$, to a double sideband suppressed carrier at $\phi = 180^\circ$ and to single sideband at $\phi = 270^\circ$. Consequently a demodulator must be capable of coping with these variations in input signal. In order to effect coherent demodulation it is necessary to provide a reference signal which conveniently can comprise the carrier or can be obtained from the double sideband signal when there is no carrier.

However a carrier locking loop will periodically lose its reference, and hence lock, when the resultant carrier nulls to zero. Similarly a system which derives the carrier information from the sidebands will also lose lock when one of the sidebands is zero. This will be illustrated with reference to Figures 1 and 2 of the accompanying drawings which show two known types of demodulator.

The block schematic circuit shown in Figure 1 is known as the 2F, or squaring, loop and comprises an input terminal 10 to which a sideband diversity signal is supplied. This signal is squared in a squaring circuit 12 and the output is filtered in a bandpass filter 14 and applied to one input of a mixer 16. The mixer 16 forms a part of a phase lock loop 18. The loop 18 includes a local oscillator 20 whose frequency is adjustable in response to an error voltage. The output of the oscillator 20 is multiplied by two in a multiplier 22 and applied as a second input to the mixer 16. The output of the mixer 16 is applied to a low pass filter 24 which produces a voltage which is used for adjusting the frequency of the oscillator 20.

In operation with a sideband diversity input signal as described by Equation 2, the signal obtained from the carrier after squaring and bandpass filtering is:-

$$(1 + \cos \phi(t)) \cos 2\omega_c t \quad \dots(3),$$

the carrier signal derived from the sidebands is:-

$$(0.5 \cos \phi(t)) \cos 2\omega_c t \quad \dots(4),$$

and the composite carrier signal is therefore:-

$$(1 + 1.5 \cos \phi(t)) \cos 2\omega_c t \quad \dots(5).$$

This composite signal no longer has a single null at $\phi = 180^\circ$ but two nulls occurring at $\phi = 132^\circ$ and $\phi = 278^\circ$. The phase lock loop will lose lock at these phase angles and is therefore not suitable for sideband diversity operation.

The block schematic circuit shown in Figure 2 is known as a Costas loop and comprises an input terminal 10 to which the sideband diversity input signal is applied. The input signal is applied to a first input of respective first and second mixers 26, 28. A local oscillator 30 in the form of a voltage controlled oscillator is connected to the second input of the first mixer 26 and, via a 90° phase shifter 32, to the second input of the mixer 28. The outputs of the mixers 26, 28 are applied to respective bandpass filters 34, 36 which pass the sideband signal components from the respective mixers. These sideband components are mixed in a further mixer 38 to produce an error signal E_s . This error signal E_s is filtered in a low pass filter 40 to provide a voltage for adjusting the frequency of the local oscillator 30 as desired.

With a sideband diversity input signal as described by Equation 2 the Costas loop produces an error signal E_s from the sidebands described by:-

$$E_s = m^2 V^2 / 8 \cos \phi \sin 2\theta \quad \dots(6)$$

where θ is the phase error in the local oscillator.

If desired an error signal can be obtained from the carrier by replacing the bandpass filters 34, 36 in the loop arms by low pass filters. The composite signal so derived suffers from the same problems as those described for the 2F loop and the loop will lose lock at specific values of ϕ .

Accordingly it is an object of the present invention to be able to provide a carrier locking loop which will remain locked for all values of $\phi(t)$.

According to one aspect of the present invention there is provided a method of demodulating a double sideband amplitude modulated signal in a quasi-synchronous area coverage scheme utilising sideband diversity, comprising producing a composite error signal from a received, frequency converted signal, the composite error signal comprising a first error signal derived from a carrier or IF carrier signal and a second error signal derived from the sidebands in the signal, and utilising the composite error signal to lock the frequency of a frequency controllable local oscillator used in demodulating the received signal.

According to another aspect of the present invention there is provided a receiver for receiving and demodulating a double sideband amplitude modulated signal in a quasi-synchronous area coverage scheme utilising sideband diversity, the receiver comprising at least one frequency conversion stage and an IF demodulating stage including means for producing a composite error signal comprising a first error signal derived from an input signal to the IF stage and a second error signals derived from sidebands of the input signal, the composite error signal being used to lock the frequency of a frequency controllable local oscillator

provided in the frequency conversion stage of the IF stage to the carrier frequency present at the input of said stage.

An advantage of the present invention over the prior art proposals is that the first error signal forms a carrier tracking loop so that the composite error signal is different and the phase error in the oscillator is able to track from 0 to 90° for values of ϕ between 90° and 180°. Consequently the information derived from the carrier and from the average of the sidebands reinforces each other rather than cancels and in consequence the data is preserved.

The composite error signal may be applied to a voltage controlled local oscillator of the IF stage or alternatively to a voltage controlled local oscillator of a preceding frequency conversion stage. In the latter case the gain of the voltage controlled local oscillator may be increased.

The present invention will now be described, by way of example, with reference to Figures 3 to 7 of the accompanying drawings, wherein:

Figure 3 is a diagram showing the combined spectra for an amplitude modulated quasi-synchronous (AMQS) signal and a sideband diversity (SBD) signal,

Figure 4 is a block schematic circuit diagram of a radio receiver made in accordance with the present invention,

Figure 5 are graphs illustrating error signal amplitudes for different values of R.F. phase angle ϕ ,

Figure 6 is a vector diagram of the lower sideband (LSB) and upper sideband (USB) components and the resultant (R) demodulated signal, and

Figure 7 is a schematic circuit diagram of an embodiment of a demodulator for a radio receiver in accordance with the present invention.

In Figure 3 the carrier signal is referenced f_c and the sideband signals $-f_m$ and $+f_m$ are spaced equally from f_c . Looking first at the AMQS spectra it will be noted that as the R.F. phase angle ϕ varies between 90° and 270° the amplitude of the received signal diminishes to zero (that is below the threshold of the radio receiver) at 180°, consequently a carrier locking loop will drop out of lock and any data being transmitted would be lost. In contrast the SBD spectra shows that for $\phi = 0^\circ$ there is a conventional AM signal, for $\phi = 90^\circ$ there is a single (lower) sideband signal, for $\phi = 180^\circ$ there is a double sideband, suppressed carrier signal and for $\phi = 270^\circ$ there is a single (upper) sideband signal. Consequently not only is there a signal always present but also it is possible to provide a carrier locking signal, in the case of $\phi = 180^\circ$ this locking signal can be derived from the sidebands.

Figure 4 is a block schematic circuit diagram of a receiver including a demodulator that can remain in lock for values of between 0° and 360°. The receiver includes an aerial 42 connected to an R.F. section 44, the output of which is an IF signal with sideband diversity. This IF signal is applied to a demodulator 46 comprising first and second mixers 48, 50. Also supplied to the mixer 50, is a signal derived from a local oscillator 52, in the case of the signal applied to the mixer 50, it is shifted in phase by 90° in a phase shifter 54. The audio signals in the outputs of the mixers 48, 50 are derived by bandpass filters 56, 58. An error signal, E_s , can be obtained from the audio signals by mixing the outputs of the filters 56, 58 in a mixer 60. The error signal E_s is then filtered in a low pass filter 62.

An error signal, E_c , can be obtained from the carrier signal component from the mixer 48 by means of a low pass filter 64. The two error signals E_s and E_c are combined in a summing circuit to provide a composite error signal E_{cs} which is applied to the local oscillator 52 to lock its frequency to the carrier frequency.

The audio signal, for example speech and/or data, is derived from the output of the bandpass filter 58 by means of and A.F. section 68, the output of which is applied to the appropriate transducer 70 or data processing apparatus 72.

In operation the output of the filter 62 will be the error signal, E_s , derived from the sidebands and described by Equation (6) while the output of the filter 64 will be the error signal E_c , derived from the carrier and described by:-

$$E_c = v \cdot \cos \phi / 2 \cdot \sin \theta \quad \dots(7)$$

E_s is a function of $\cos \phi$ and E_c a function of $\cos \phi / 2$ because of the behaviour of the input signal. E_s is also a function of $\sin 2\theta$ while E_c is a function of $\sin \theta$ and with a single input signal ($\phi = 0^\circ$) either error signal could be used to maintain lock at $\theta = 0^\circ$.

When the two error signals are combined in the summing circuit 66 then lock will be maintained at $\theta = 0^\circ$ for $\phi = 0^\circ$ but the phase reference will change as ϕ varies the relative amplitudes (and signs) of the two error signal components E and E_c .

With the gain of the low pass filters 62, 64 adjusted such that the contribution of the two error signals to the slope of the phase characteristic around $\theta = 0^\circ$ ($\phi = 0^\circ$) is equal then there is no possibility of lock occurring at $\theta = 180^\circ$ with a single input. Under these conditions the composite error signal, E_{cs} is given by:-

$$E_{cs} = K \cos \phi \cdot \sin 2\theta + 2K \cos \phi / 2 \cdot \sin \theta \quad \dots(8)$$

This signal is illustrated in Figure 5 for various values of ϕ , where it can be seen from the upper drawing that the consequences of combining the two error signals E_s and E_c is an increase in the slope of the phase characteristic over the region of interest. In Figure 5 the ordinate represents the error signal amplitude and

the abscissa the phase error θ of the local oscillator.

Referring to the lower drawing as ϕ varies from 0° to 90° the component of the error signal derived from the sidebands will be reduced (to zero at $\phi = 90^\circ$) and the slope of the phase characteristic will be decreased but the loop will maintain lock at $\theta = 0^\circ$.

- 5 As ϕ increases further from 90° to 180° the sideband derived component E_s of the error signal E_{cs} will increase but with its phase reversed while the carrier component E_c decreases. The stable null at $\theta = 0^\circ$ will change to an unstable one (at $\phi = 120^\circ$) and the loop will shift its phase reference to $\theta = 90^\circ$ (or -90°) at $\phi = 180^\circ$ the stable null will shift towards $\theta = 180^\circ$ at $\phi = 270^\circ$ and will maintain this value of θ as ϕ increases to 360° . The tracking of the phase reference takes place in the summing circuit 66. By being able to track the
10 phase reference, cancellation of the sidebands is avoided and coherent demodulation is maintained.

- The demodulated output of the loop which is supplied to the AF section 68 is just the input signal described by Equation (2) multiplied by $\cos(\omega_c t + \theta)$, where θ takes on the values described above, with the resultant signal passed through a bandpass filter. The vector components of the demodulated signal are shown in Figure 6. In Figure 6 the lower and upper sideband components are designated LSB and USB
15 respectively and their resultant as R. As ϕ varies between 0° and 360° there is no null in the demodulated signal, the amplitude variations being restricted to between 3 and 6 dB.

There is however an unavoidable phase shift of $\theta = 90^\circ$ (which is relatively slow compared with the data rate), which may effect some forms of data modulation.

- From laboratory tests of comparing the sideband diversity demodulator used in a receiver made in
20 accordance with the present invention with a conventional AM demodulator using audio frequency, frequency shift keying (FSK) at a data rate 1200 bits/second, it was shown that the sideband diversity demodulator is better than the A.M. demodulator by about 8 dB at low signal levels when one signal only is being received; the error rate falling sharply in both cases as the signal level is increased.

- When two equal signals (with an offset of 2 Hz) are applied however, the results were very different.
25 Although the sideband diversity performance was degraded by approximately 10 dB the error rate still improved rapidly as the signal level increased giving an error rate of 2.6×10^{-6} for signal levels less than 1 μ V (p.d.). With conventional Q.S. operation the error performance is extremely poor and improves only slightly with signal level. Similar results were obtained for equal signals with offset frequencies up to 30 Hz.

- In the receiver illustrated in Figure 4 the 90° phase shifter 54 may be replaced by say a $+45^\circ$ phase shifter
30 and a -45° phase shifter or any other combination of phase shift angles totalling 90° . Alternatively the local oscillator 52 output may be applied directly to both mixers 48, 50 and the IF signal applied to one of the mixers 48 or 50 being shifted in phase by 90° relative to the IF signal applied to the other of the mixers 50 or 48. Irrespective of the actual means used, it is necessary to ensure a relative phase difference of 90° between the outputs of the mixers 48, 50.

- Referring now to Figure 7 which illustrates an embodiment of a demodulator for a receiver made in
35 accordance with the present invention. Unlike the receiver shown in Figure 4, the composite error signal E_{cs} is used to adjust the carrier frequency of a voltage controlled crystal oscillator (VCXO) of the first or second conversion oscillator rather than the single frequency crystal oscillator in the illustrated embodiment.

- In Figure 7 a 455 kHz IF signal is applied to an input 74 from where it is applied to first and second mixers
40 76, 78 constituted by switches. A relative phase shift of 90° is produced in the signal applied to the respective inputs of the mixers 76, 78 by phase shifting networks 80, 82, the network 80 being of integrating type and the network 82 of differentiating type. A 455 kHz crystal local oscillator 84 is also connected to the mixers 76, 78. Since the incoming signals undergo a relative phase shift of 90° then it is necessary to shift the phase of the output of the local oscillator 84.

- 45 The outputs of the mixers 76, 78 are low pass filtered in filters 86, 88 and their outputs are passed via buffer amplifiers 90, 92 to the inputs of high pass filters 94, 96 which pass the audio signals. The filters 94, 96 comprise amplifiers 95, 97 whose inverting inputs receive the signal from the buffer amplifiers 90, 92, respectively, and whose non-inverting inputs receive a reference voltage V_R . The two audio signals are mixed in a double balanced mixer 98 to provide the sideband error signal E_s which is amplified in amplifier
50 100 before being applied to a summing input 102 of a summing amplifier 104.

- The carrier error signal E_c derived from the output of the buffer amplifier 90 is also applied to the summing
input 102. The output, composite error signal, E_{cs} , of the summing amplifier 104 appears on a terminal 106 from where it is used to adjust the frequency of a VCXO of an earlier converter stage, usually the second converter stage. One advantage of operating on a second converter stage as opposed to the IF stage is that
55 the loop gain can be greater.

In the case of the embodiment illustrated the components used are of the following type or have the following values:

5					
	R1	820	R5	5.1K	
	R2	3.9K	R6	1M	
5	R3	1.0K	R7	7.5K	5
	R4	5.1K	R8	33K	
	R9	11K	R17	220K	
10	R10	240K	R18	8.2K	10
	R11	10K	R19	1K	
15	R12	75K	R20	1K	15
	R13	10K	R21	8.2K	
	R14	75K	R22	680K	
20	R15	5.6K	R23	82K	20
	R16	220K	R24	10K	
25					25
	C1	560 pF	C9	33 nF	
	C2	560 pF	C10	33 nF	
30	C3	0.01 μ F	C11	3.3 nF	30
	C4	0.01 μ F	C12	33 nF	
	C5	47 pF	C13	2.2 μ F	
35	C6	47 pF	C14	2.2 μ F	35
	C7	33 nF	C15	56 nF	
40	C8	33 nF			40

Mixers 76, 78 - Semiconductor switch type 4016
Double balance mixer 98 - Texas Instruments 76514
Amplifiers 90, 92, 95, 97 - Op amp type SN 72558
Amplifiers 100, 104 - Op amp type SN 72044
Oscillator 84 - CD 4001

The reference voltage V_R applied to the non-inverting inputs of the amplifiers 95, 97 of the high pass filters 94, 96 and the amplifier 100 is derived from a 12 volt supply by a zener diode ZD and series resistor R25.

Although the present invention has been described with reference to an area coverage system comprising two spaced transmitters, a greater number of transmitters may be used. In the case of three transmitters the phase difference between the modulating signals could be $\pm 120^\circ$.

CLAIMS

1. A method of demodulating a double sideband amplitude modulated signal in a quasi-synchronous area coverage scheme utilising sideband diversity, comprising producing a composite error signal from a received, frequency converted signal, the composite error signal comprising a first error signal derived from a carrier or IF carrier signal and a second error signal derived from the sidebands in the signal, and utilising the composite error signal to lock the frequency of a frequency controllable local oscillator used in demodulating the received signal.

2. A method as claimed in Claim 1, wherein the received, frequency converted signal is the IF signal which is mixed in quadrature with a local oscillator frequency in two mixers to provide first and second output signals having a relative phase difference of 90° therebetween, the first error signal is derived by low pass filtering the output of one of the two mixers and the second error signal is derived by audio frequency filtering the outputs of the two mixers, mixing the filtered outputs and low pass filtering the output of the

latter mixing operating.

3. A method as claimed in Claim 1 or 2, wherein the composite error signal is the sum of the first and second error signals.

4. A method as claimed in Claim 1, 2 or 3, wherein the composite error signal is used to lock the frequency of the IF local oscillator signal to the converted carrier signal at an input of the IF stage. 5

5. A method as claimed in Claim 1, 2 or 3, wherein the composite error signal is used to lock the frequency of a local oscillator of a frequency conversion stage preceding the IF stage.

6. A method of demodulating a double sideband amplitude modulated signal in a quasi-synchronous area coverage scheme utilising sideband diversity, substantially as hereinbefore described with reference to 10 Figures 3 to 7 of the accompanying drawings. 10

7. A receiver for receiving and demodulating a double sideband amplitude modulated signal in a quasi-synchronous area coverage scheme utilising sideband diversity, the receiver comprising at least one frequency conversion stage and an IF demodulating stage including means for producing a composite error signal comprising a first error signal derived from an input signal to the IF stage and a second error signal 15 derived from sidebands of the input signal, the composite error signal being used to lock the frequency of a frequency controllable local oscillator provided in the frequency conversion stage or the IF stage to the carrier frequency present at the input of said stage. 15

8. A receiver as claimed in Claim 7, wherein the IF stage comprises first and second mixers, each having a first input for an input signal to be demodulated and a second input for a local oscillator signal, for shifting 20 the phase of the input signal or local oscillator such that there is a relative phase difference of 90° between the outputs of the first and second mixers, low pass filtering means coupled to an output of the first mixer, the output of the low pass filtering means providing the first error signal, first and second audio filters connected respectively to the outputs of the first and second mixers, a further mixer coupled to outputs of the first and second audio filters and further low pass filtering means connected to the output of the further 25 mixer to provide the second error signal. 25

9. A receiver as claimed in Claim 8, wherein the gains of the low pass filtering means are adjusted so that the contributions of the first and second error signals to the slope of the phase characteristic around $\theta = 0^\circ$ is equal.

10. A receiver as claimed in Claim 7, 8 or 9, further comprising summing means having inputs for receiving the first and second error signals and an output on which the composite error signal appears. 30

11. A receiver as claimed in any one of Claims 7 to 10, wherein the composite error signal is applied to a voltage controllable local oscillator of the IF stage.

12. A receiver as claimed in any one of Claims 7 to 10, wherein the composite error signal is applied to a voltage controllable local oscillator of the frequency conversion stage.

35 13. A receiver for demodulating an AM double sideband modulated signal in a quasi-synchronous area coverage scheme utilising sideband diversity, constructed and arranged to operate substantially as hereinbefore described with reference to Figures 3 to 7 of the accompanying drawings. 35

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